Physics-based Distributed Hydrologic Modeling for Flood Forecasting

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Topic

1. Introduction
2. Forecast System Overview
3. V*flo*™ Features
4. Model Overview and Demonstrations

Vieux & Associates, Inc.

We bring the atmosphere to earth.

Established in 1992, Vieux & Associates, Inc. is located in Norman, Oklahoma. Vieux & Associates, Inc. is a technology development company providing GIS, hydrology, and radar rainfall services to the public and private sectors in the US and internationally.

Expertise in these three areas supports development of customized flood alert and rainfall monitoring and analysis services.

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Course Description

Distributed Hydrologic Modeling Applications

Distributed hydrologic models represent the spatial variability of the atmosphere and land surface characteristics that control the rainfall-runoff process. Physics-based approaches are capable of using geospatial information directly. Rapid development of sophisticated computer programs capable of using the rich information content of remotely sensed geospatial data describing vegetative cover or soil moisture; distributed maps of precipitation derived from gauges, radar, and satellite (multisensor); and digital terrain maps representing the drainage network. The foundation for *accurate* hydrologic prediction is the *accurate* representation of precipitation input and the terrestrial characteristics that transform rainfall into runoff.

Physics-based distributed hydrologic models are an emerging trend in hydrologic practice. Flood warnings in urban and regional areas subject to flooding are beginning to use physics-based distributed hydrologic models in operational schemes. Hydrologic prediction and flood warning systems rely on multisensor precipitation and geospatial data to provide critical flood information for decision-making and operations.

The material presented is an excerpt form a course on Distributed Hydrologic Model for Flood Forecasting. Tutorials are presented that demonstrate principles of physics-based modeling and concepts. Software, sample data, and tutorial help files are provided for illustrative purposes and conducting the exercises. This course is an abridged version of more detailed training in the use of the distributed model, V*flo*™. Additional information is available at www.vieuxinc.com.

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Norman, Oklahoma, USA
November 5, 2003

BIOSKETCH

Baxter E. Vieux, Ph.D., P.E. is a Full Professor in the School of Civil Engineering and Environmental Science, University of Oklahoma, Norman where he teaches courses in hydrology, geoinformatics (surveying), water quality management, engineering graphics and design. Before joining OU in 1990, he held a visiting professorship at Michigan State University teaching watershed management. Dr. Vieux was recently appointed as Adjunct Professor with the Department of Environmental Engineering and Science, Rice University, Houston. Prior to his academic career, ten years were with the USDA Natural Resources Conservation Service (formerly SCS). His highest position was acting State Engineer supervising state-wide engineering design and construction programs for flood control and drainage in Michigan. He is a registered professional engineer in three states and is principal and founder of Vieux & Associates, Inc., an engineering technology company with clients in the US and internationally in radar rainfall, GIS, and hydrology. He is the architect of the first commercially available physics-based distributed hydrologic model, V*flo*™, which uses real-time radar inputs for hydrologic analysis and prediction.

Externally sponsored research has been funded by NASA, EPA, NWS, NOAA, Army Corps of Engineers, NSF, and state/local agencies. Internationally, he has conducted research and worked on projects in France, Japan, Poland, Niger, Nicaragua, Taiwan, and Romania. He has authored over 75 publications in hydrology including a recent book, *Distributed Hydrologic Modeling Using GIS*, Kluwer Academic Press, Vol. 38. Two chapters involving radar and GIS appear in the widely-used engineering hydrology text book by Bedient and Huber, *Hydrology and Floodplain Analysis*, 3rd edition, Prentice Hall.

Physics-based Distributed Hydrologic Modeling for Flood Forecasting

HYDROLOGIC FORECASTING COURSE
National Oceanic and Atmospheric Administration
National Weather Service, and
World Meteorological Organization
14 October – 7 November 2003
Kansas City, MO, USA

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GIS ■ Hydrology
Radar Rainfall

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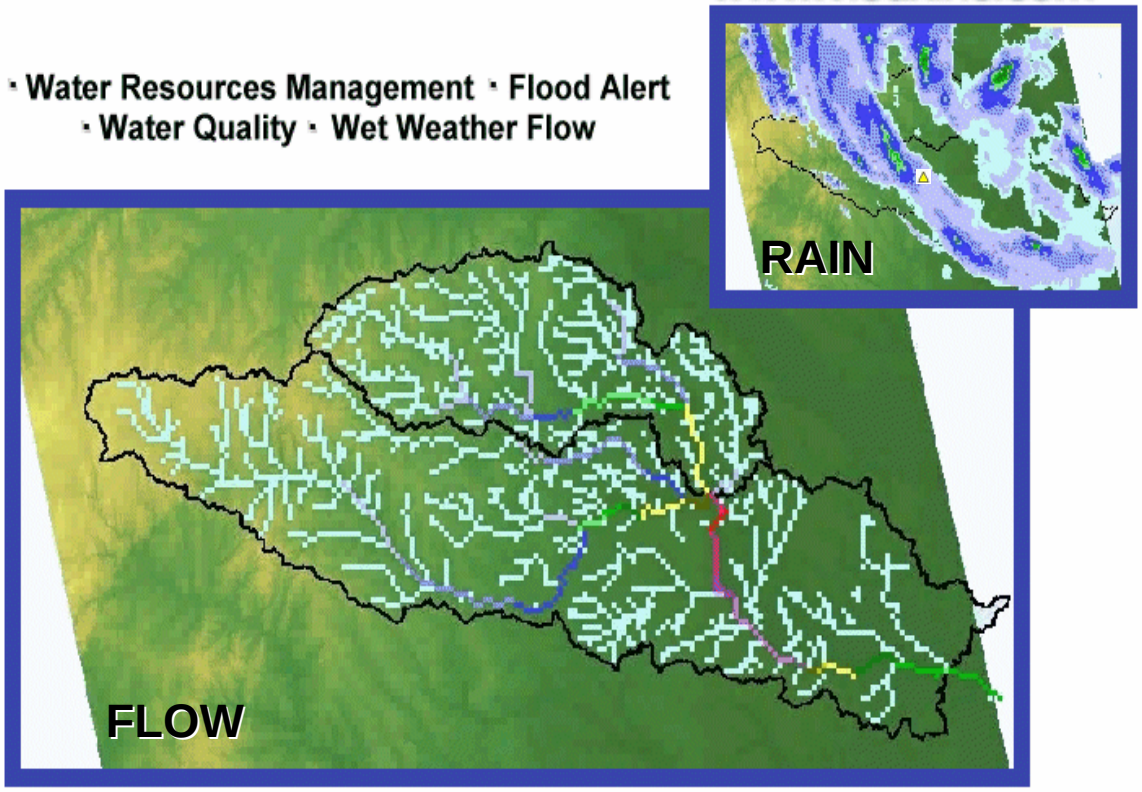
· Water Resources Management · Flood Alert
· Water Quality · Wet Weather Flow



Services

- Real-time Calibrated Radar Rainfall Systems
- Hydrologic Modeling
- Flood Alert Systems
- Rainfall and Flood Event Recreation

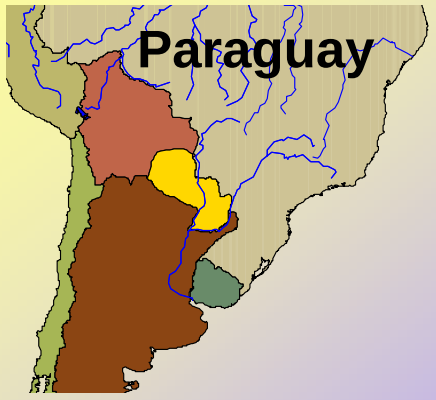
Experience and Expertise

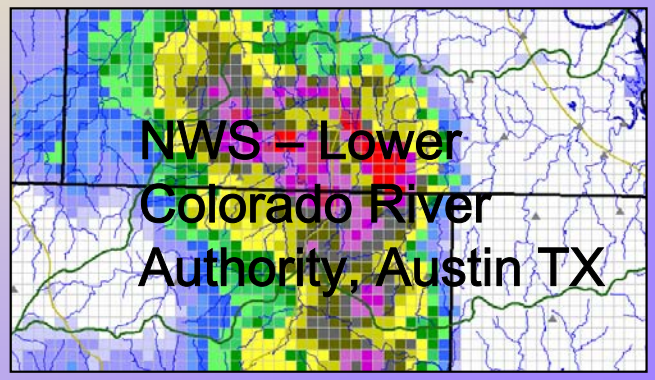
- Vieux & Associates, Inc. specializes in GIS, hydrology and radar rainfall applications in flood forecasting and water management.
- Established in 1992 as an Oklahoma Subtitle S Corporation, Vieux & Associates, Inc. is located in Norman, Oklahoma.
- Products and services to governmental and commercial sectors in the US and internationally.

Public-Private Sector Partnerships

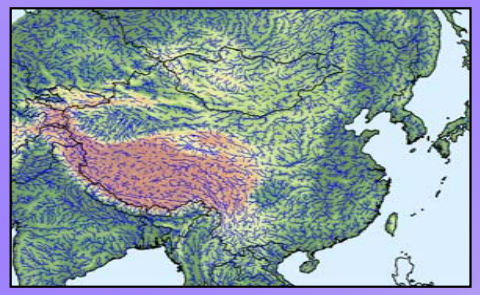
- CWB/WRA Taiwan
- NOAA/NWS Tar River
- International collaboration:
  - System planning and design
  - Rainfall processing
  - Model development
  - Training and educational opportunities

Paraguay

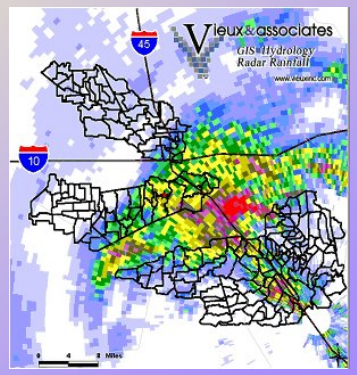




China



Houston, TX



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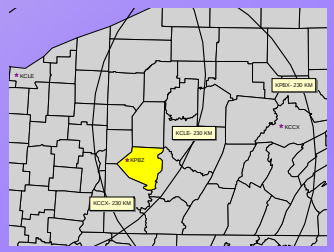
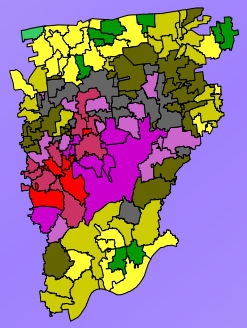


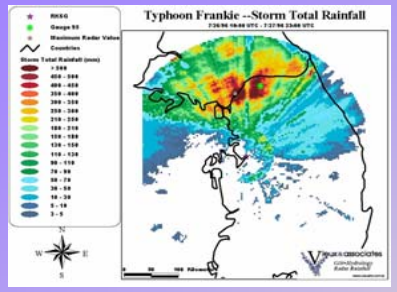
Taiwan

Romania

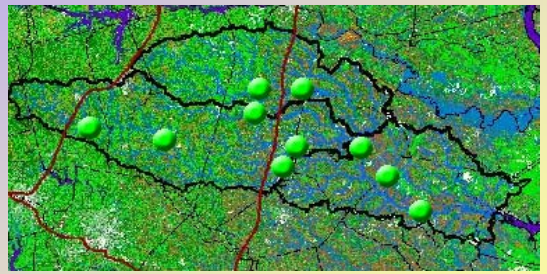
Cincinnati, OH



South Korea



North Carolina



Visit us in Norman

Forecasting System Overview

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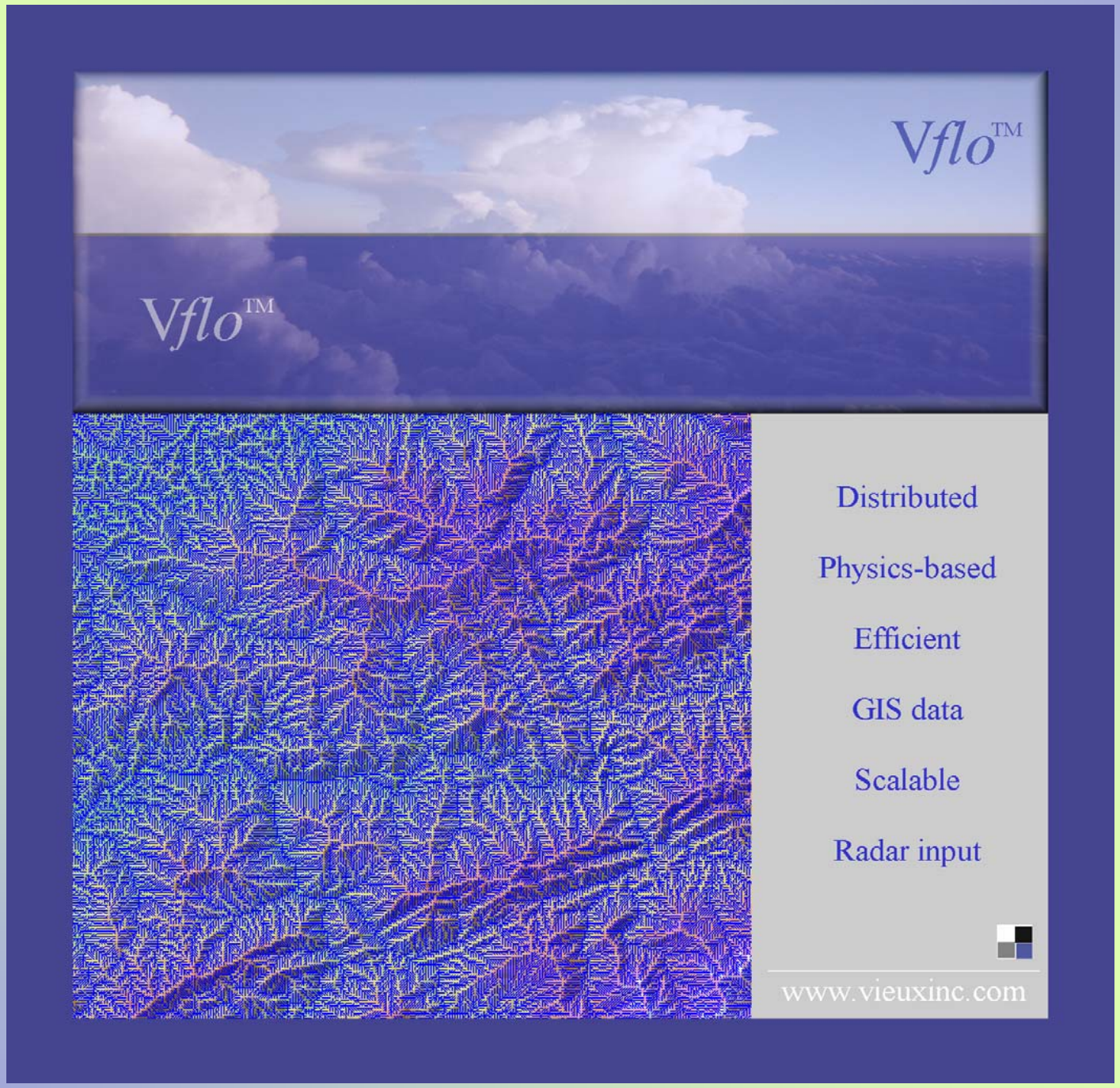
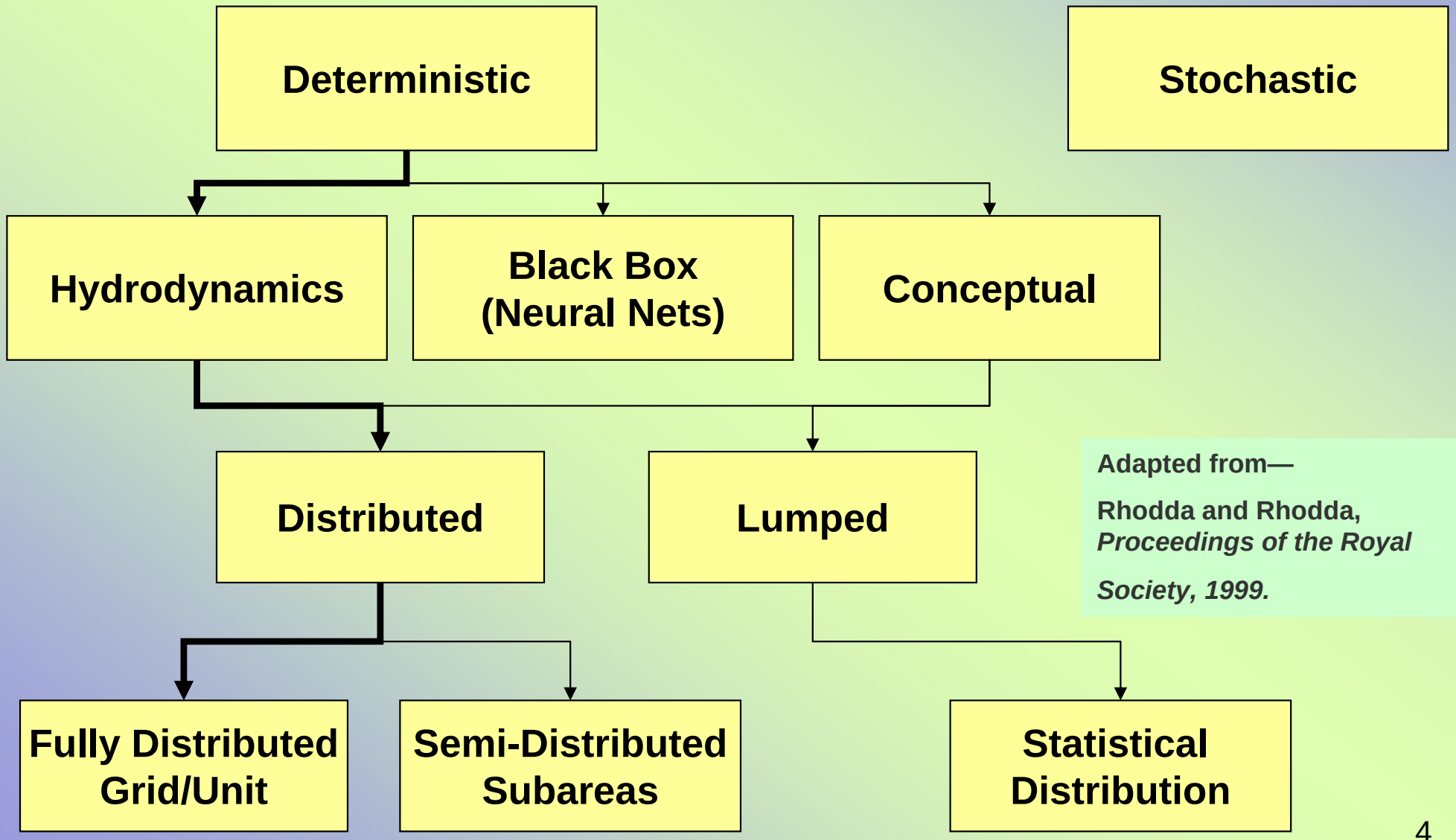


What is Distributed Hydrologic Modeling?

- Divide watershed into grid cells
- Connect cells to form a drainage network
- Use physics to predict runoff rates and volume
- GIS data to describe terrestrial features
- Inputs from radar, satellite, and rain gauge

Predict hydrologic response at any location in the drainage network

Classifying Hydrologic Models



Adapted from—

Rhodda and Rhodda, *Proceedings of the Royal Society, 1999.*

Distributed Hydrologic Analysis and Prediction

Distributed hydrologic analysis and prediction—

- Data deficiencies are reduced by radar, remote sensing, and GIS
- Modeling that use this data directly can better represent the river basin and the drainage network for making improved forecasts
- Technology helps us:
    1. Cope with voluminous amounts of data
    2. Manage conflicting demands for water
    3. Effectively use critical information during operations
    4. Conserve a precious resource

V*flo*™ Capabilities

A. GIS and spatial data—

- Shapefiles locate critical point, areal, linear features
- Import/export GIS gridded data and internal editing

B. Hydrologic forecasting—

- Hydraulic approach to distributed hydrology integrated in Java

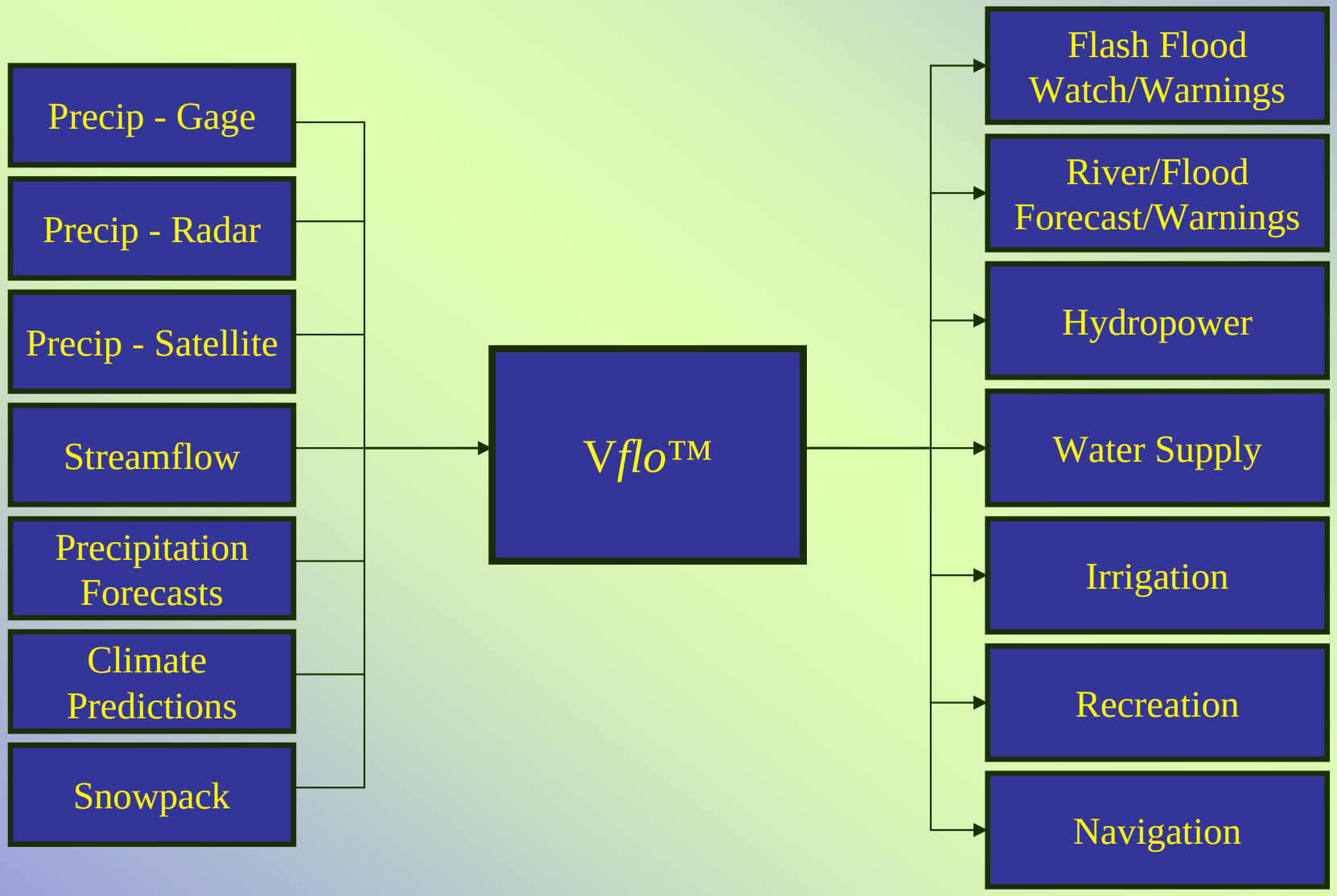
C. Flood risk and inundation mapping—

- Distributed throughout the basin in each grid cell
- Hydrographs at automated watch points
- Uses high resolution DEM and river cross-sections
- Affected cells are identified for contact information/notification

D. Operational Considerations-—

- Maintained without detailed GIS knowledge
- Results disseminated via the Internet
- Distributed architecture facilitates coordination between central and regional river basin operations

Model Inputs and Applications

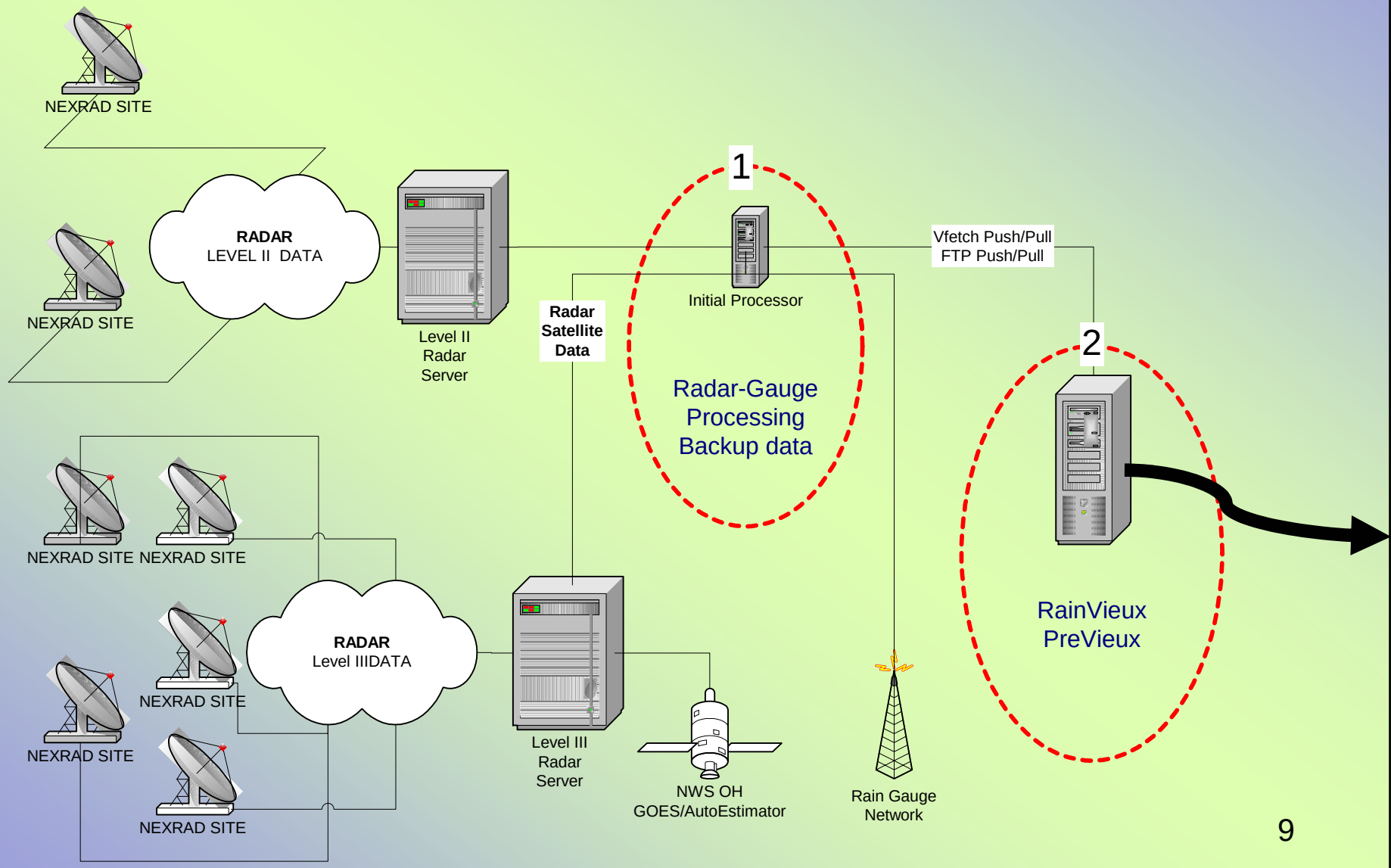


Graphical User Interface

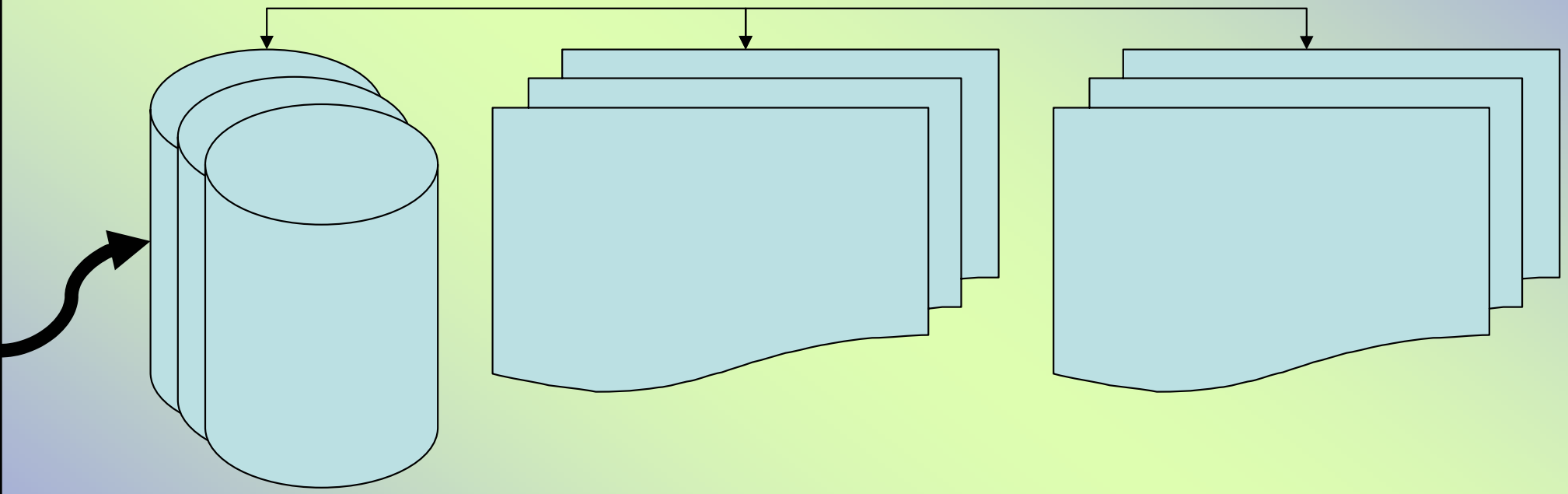
- **Model is developed from the beginning in JAVA and has integrated GUI and web-display.**
- **Multi-platform/OS capability:**

  Linux/Unix/PC Windows 2000/XP
- **Display of distributed flood risk maps for country-wide integrated operations.**
- **Existing features support integration with database and web applications.**
- **Complete implementation in a distributed architecture builds on modern (n-tier) information systems.**

DISTRIBUTED ARCHITECTURE INTERNET DATA TRANSFER



Distributed Architecture



Database Servers

Vflo Servers

Vflo Web Servers

RainVieux and V*flo*™

Integrated Flood Forecasting

- **With one model:**
  - Flash flood to river basin modeling
  - Inundation and hydrograph output
  - Distributed flood risk

V*flo*™ Features and Demonstrations

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Physics-based Distributed Flood Forecasting

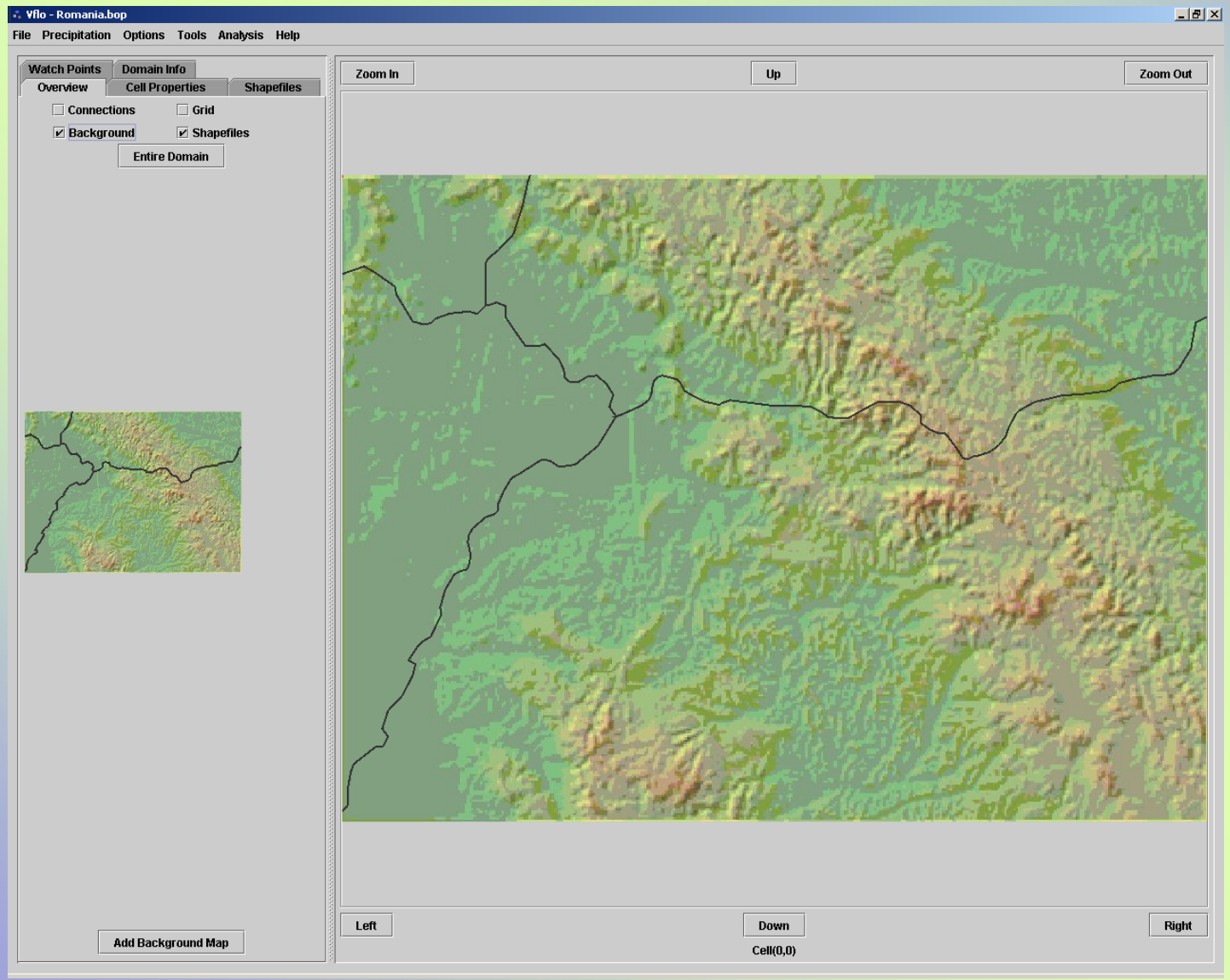
- Flow rates from conservation of mass/momentum
- V*flo*™ uses a hydraulic approach to hydrology in a tightly integrated Java environment.
- Typically, in other models, hydrologic routing is utilized on a reach-by-reach basis from upstream to downstream.
- V*flo*™ routes runoff from cell-to-cell basis in channels and overland elements
- Local or lateral inflow is accounted for automatically (not cross-section to cross-section).

Hydraulics = Hydrology

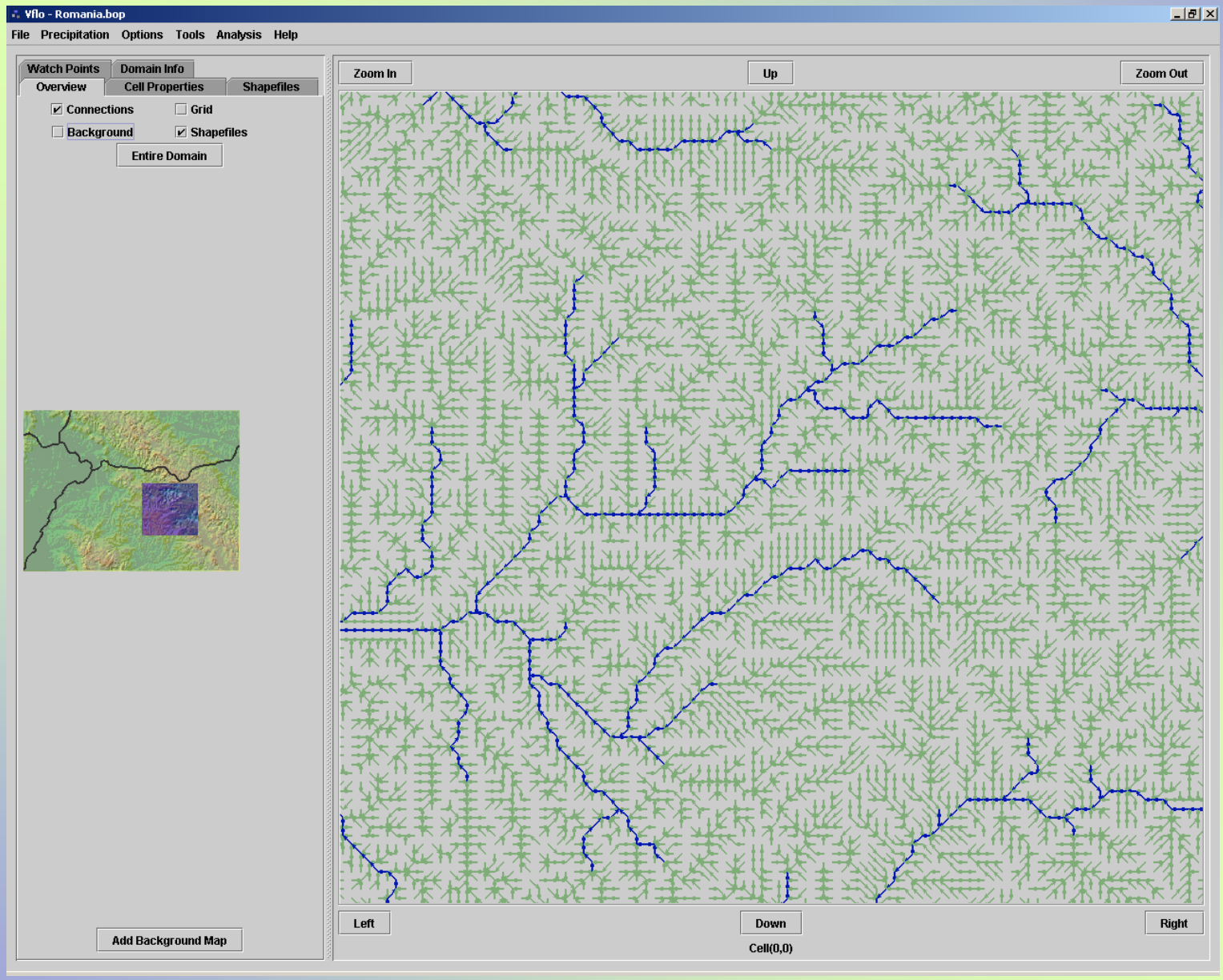
V*flo*™ Modules

- **Overview**
- **Snowmelt**
- **Routing methods**
- **Inundation mapping**
- **Contaminant transport**

Overview

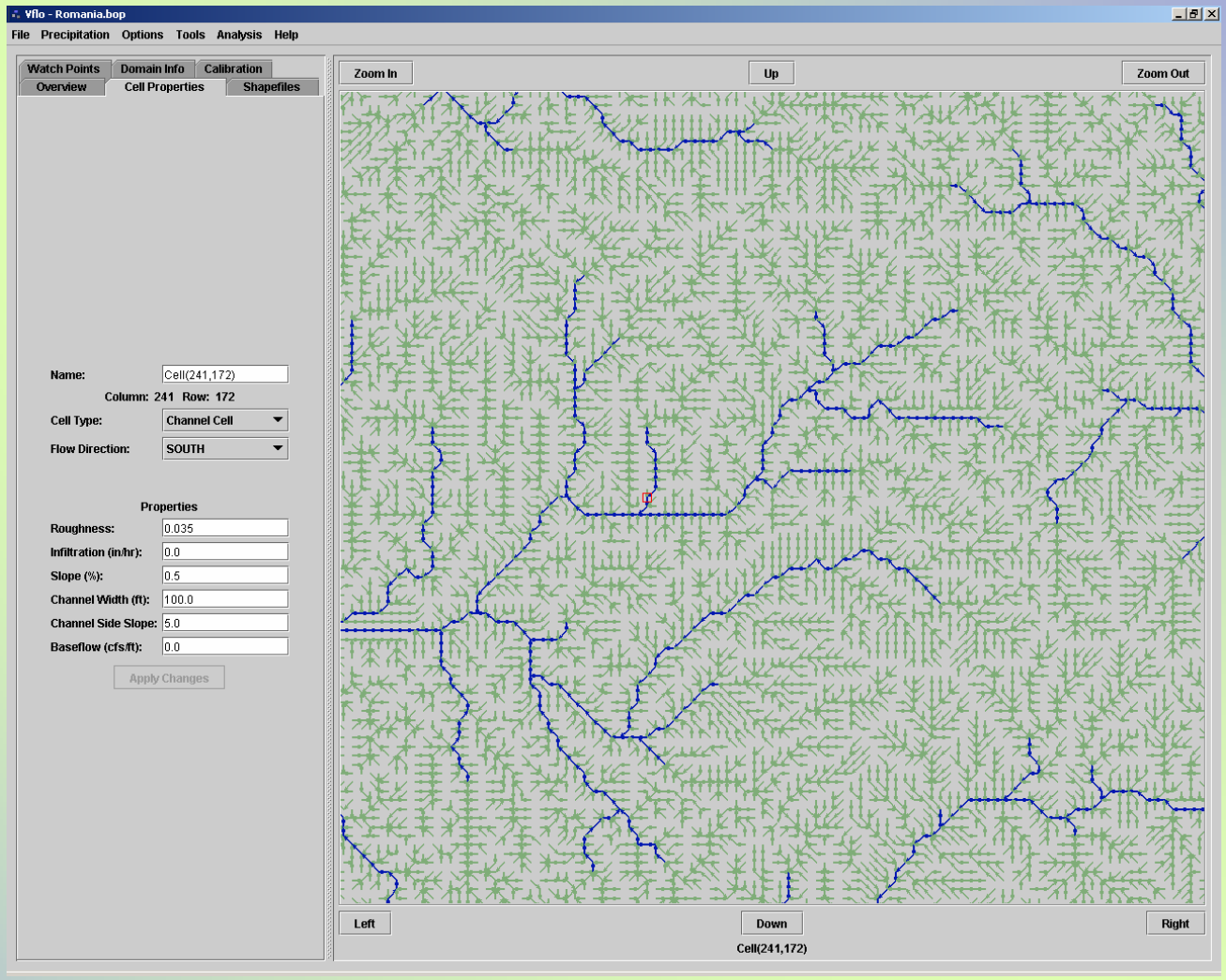


Finite Element Connections



Cell Properties

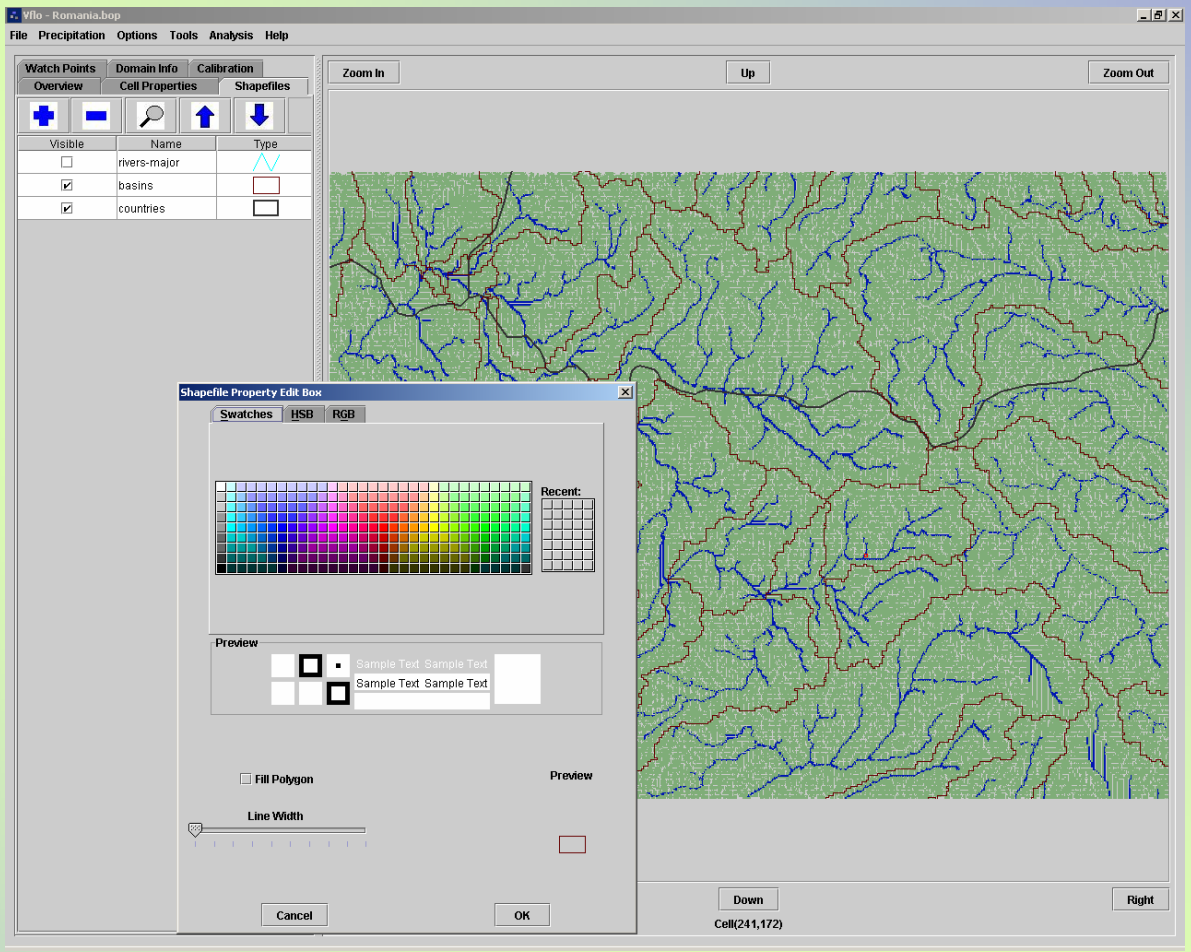
- Channel/Overland
- Hydraulic roughness
- Infiltration
- Slope
- Channel width
- Channel side slope
- Baseflow



Shapefile Overlay

Shapefile Overlay

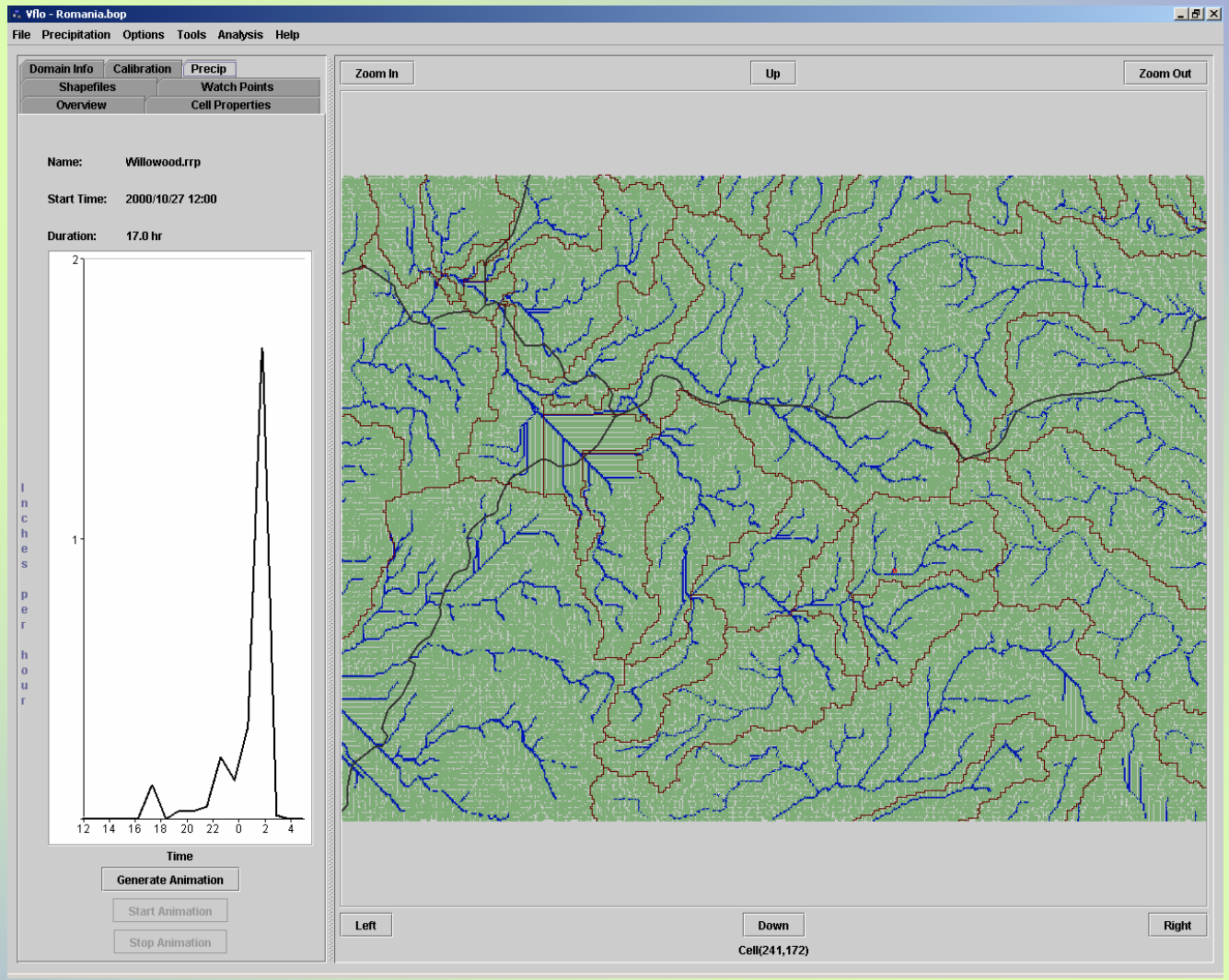
- Edit window
- Color
- Line of filled polygon
- Line width



Precipitation

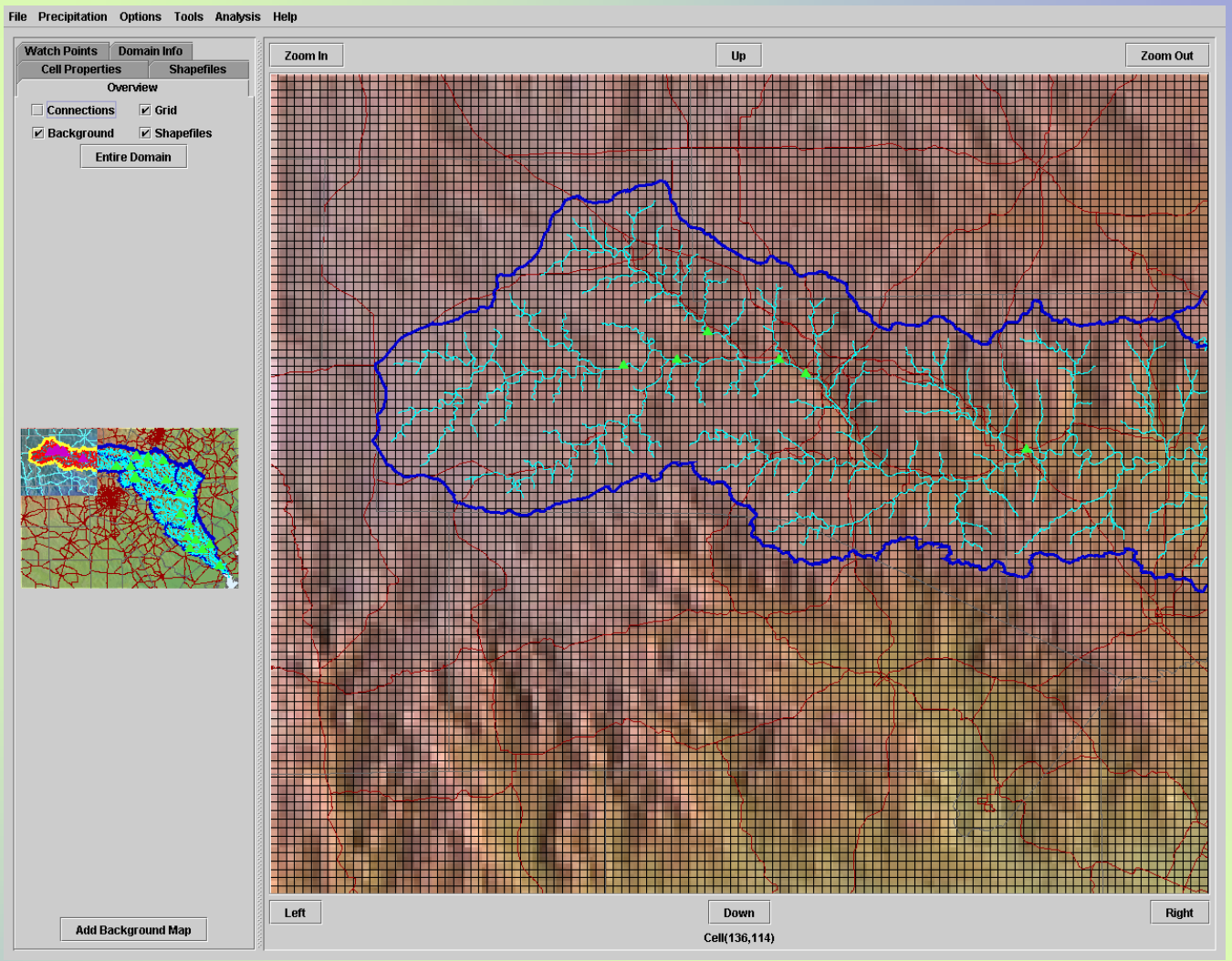
Distributed or lumped—

- Hyetograph
- Animation
- Snow/rain

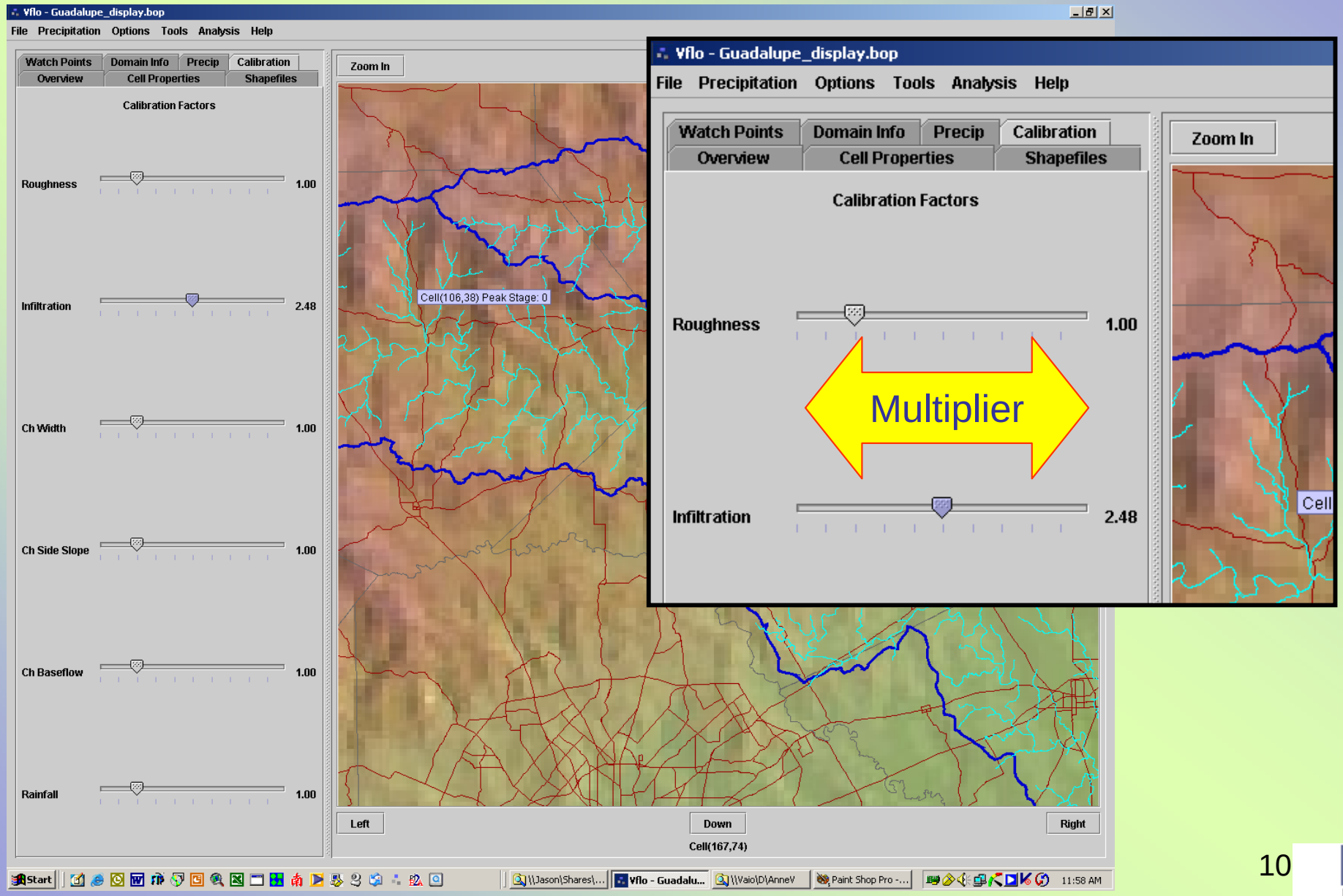


Drainage Network

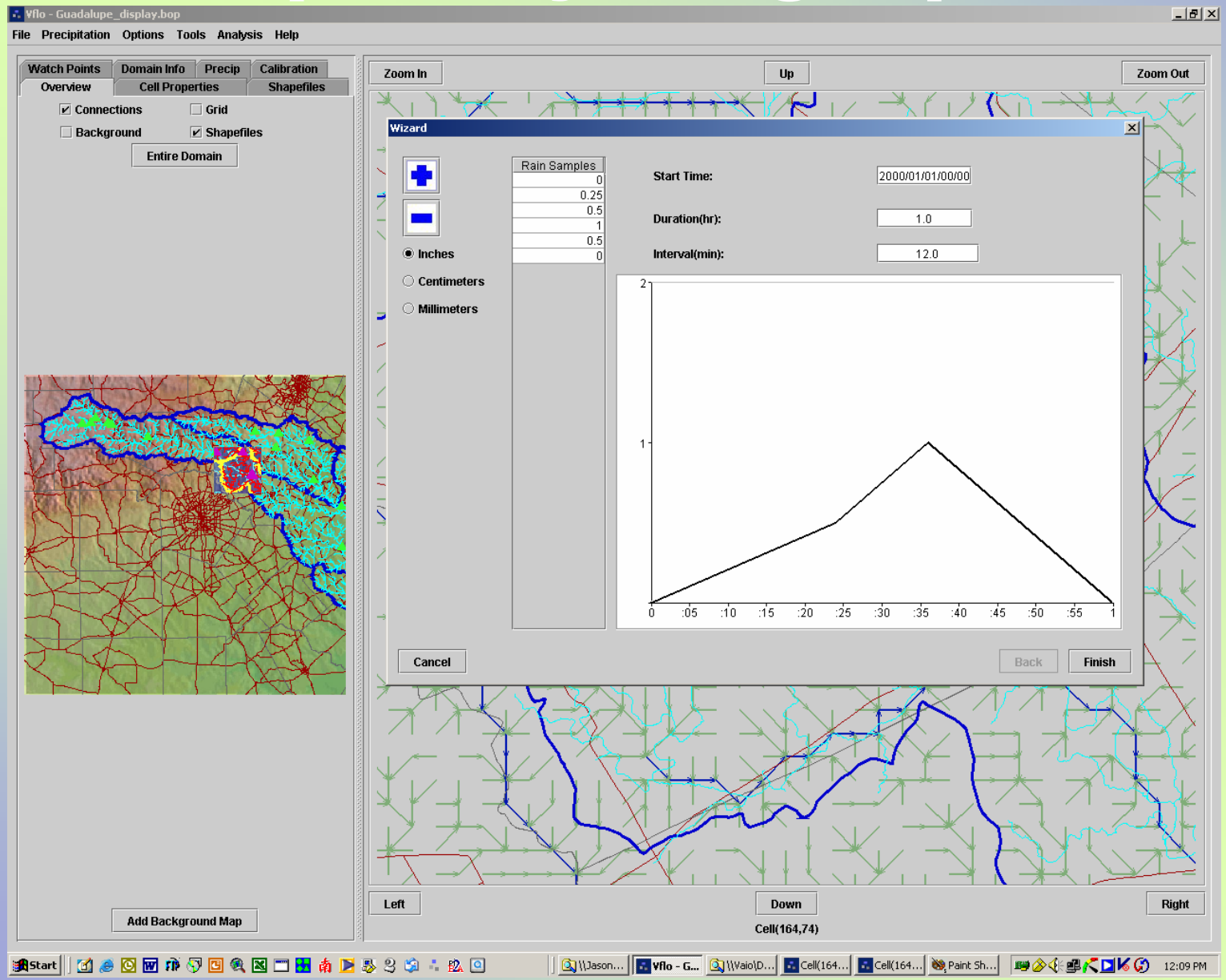
- DEM flow direction defines the connections between grid cells.
- Hydrologic response depends on the network



Distributed Calibration



Input Hyetograph



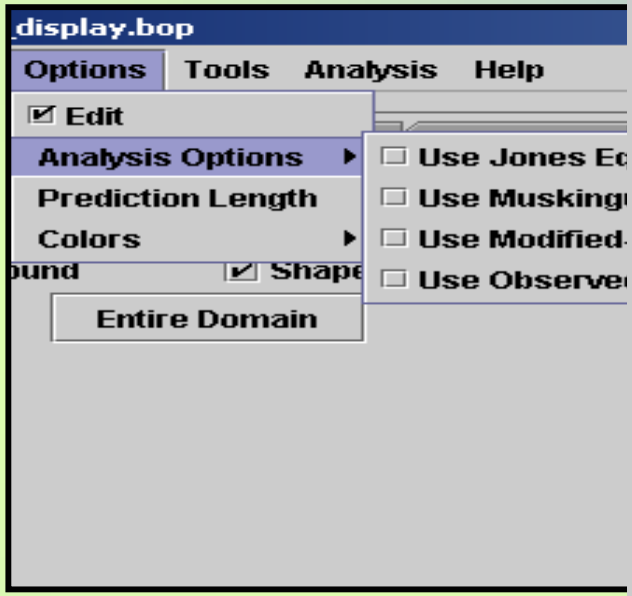
Routing Options

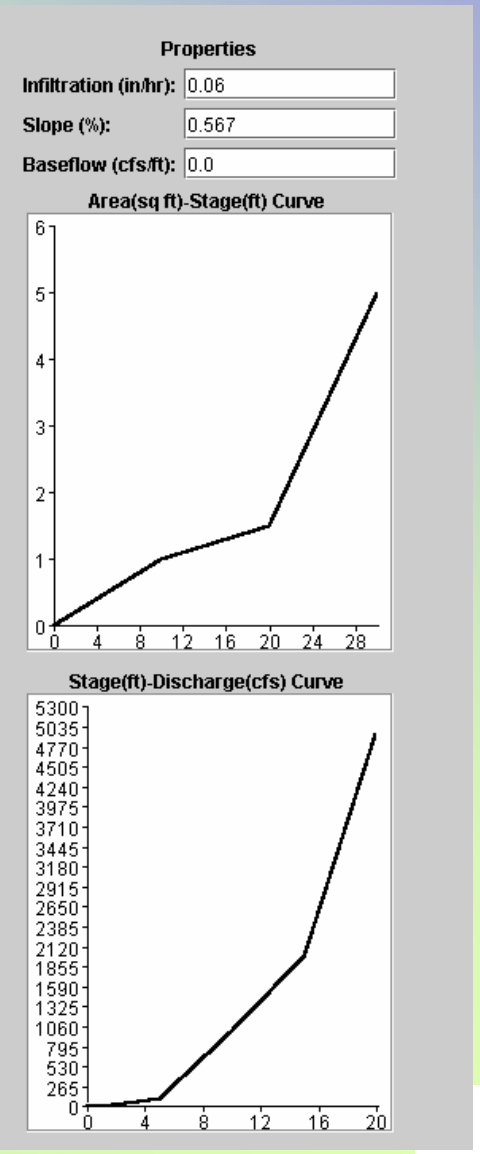
Channel routing—

- Modified Puls
- Observed
- Looped rating curve modification (Jones)
- Kinematic Wave
- Rating curves for complex hydraulics
- Cross-section (n,s)

Reservoir routing—

- Storage indication
- Controlled/uncontrolled
- Base cell (marsh/open water)

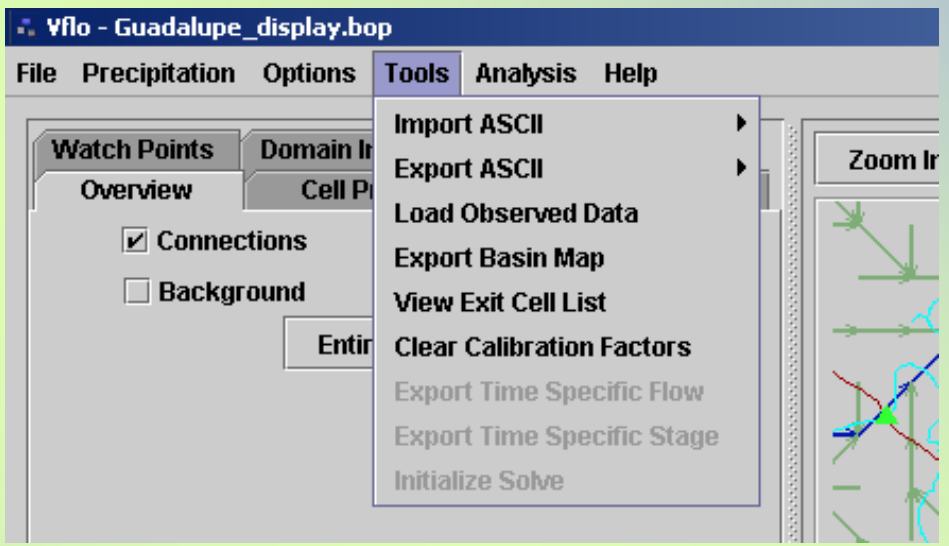




GIS Input and output

Options—

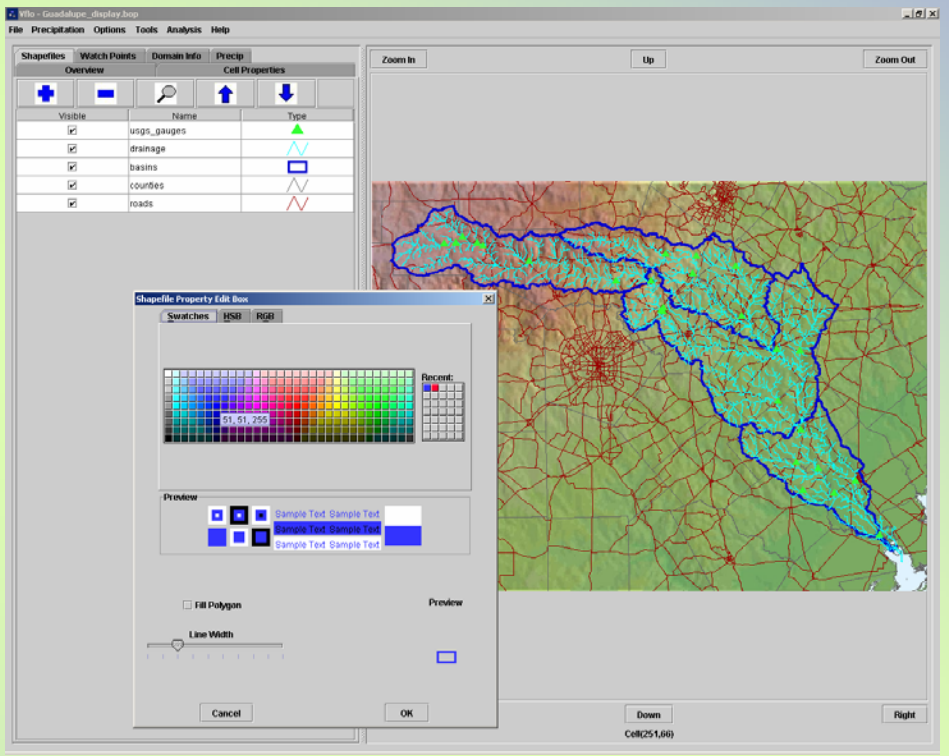
- Import ASCII grids of flow direction and all parameters
- Export grids after editing or calibration
- Deep clone calibration factors to basin properties



GIS Shapefile Overlay

Shapefile—

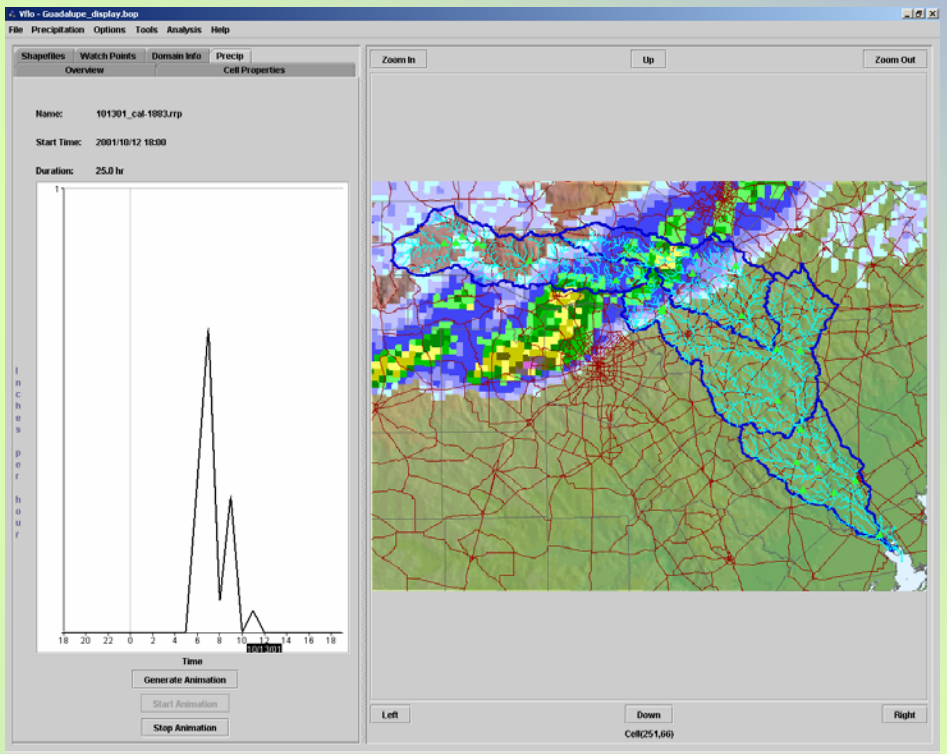
- Locate critical point, areal, linear features
- Display gauging locations, streams, roads, cities, water bodies, etc.
- Adjust color and weight
- Helpful but optional



Precipitation Input

Multisensor Precipitation—

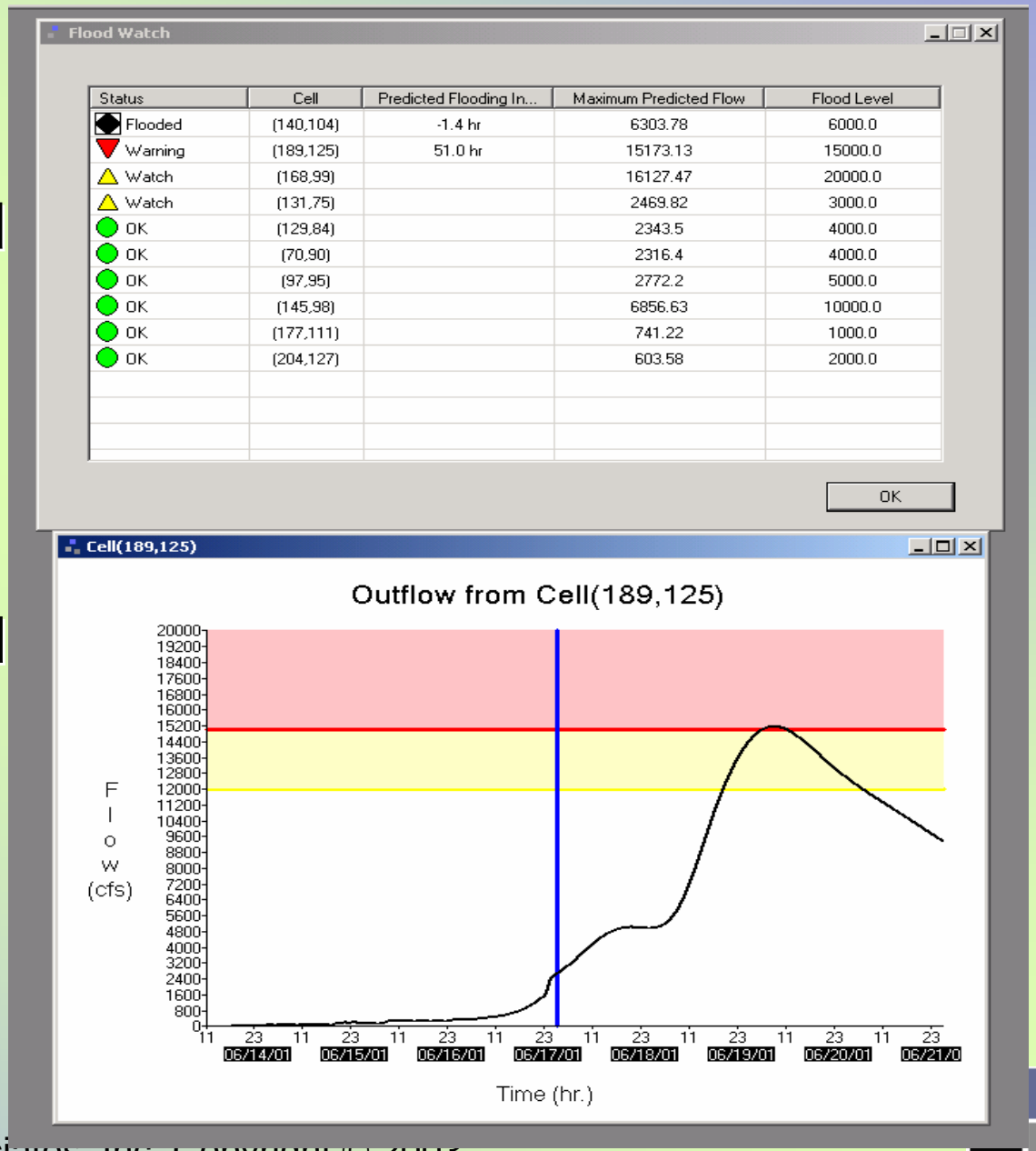
- Radar, rain gauge, satellite
- Precipitation input as grids or point values
- Snowmelt from SWE and temperature/wind
- Animations and hyetographs



Model Output

Hydrographs—

- Display at any selected location
- Set watch points to automatically generate alerts
- Plot both observed and simulated
- Web display



V*flo*™ Modules
(Version 2.1)

Snowmelt

Temperature Index Snowmelt

Practical forecast applications use this method almost exclusively:

$$M = C (Ta - Tb)$$

where M is the snowmelt depth per period;

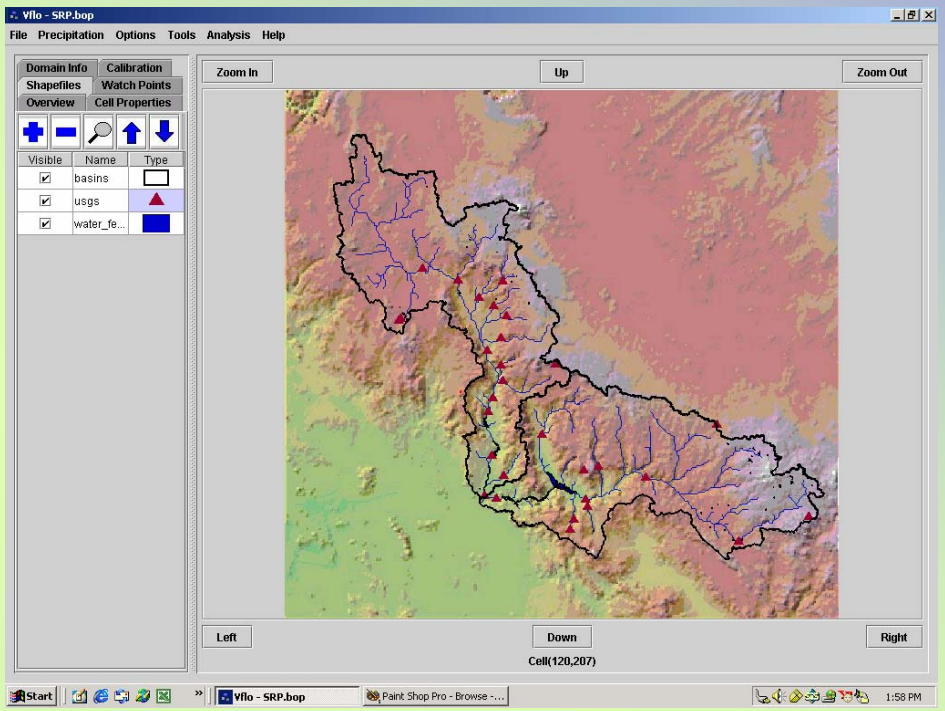
C is the melt rate coefficient;

Ta = air temperature

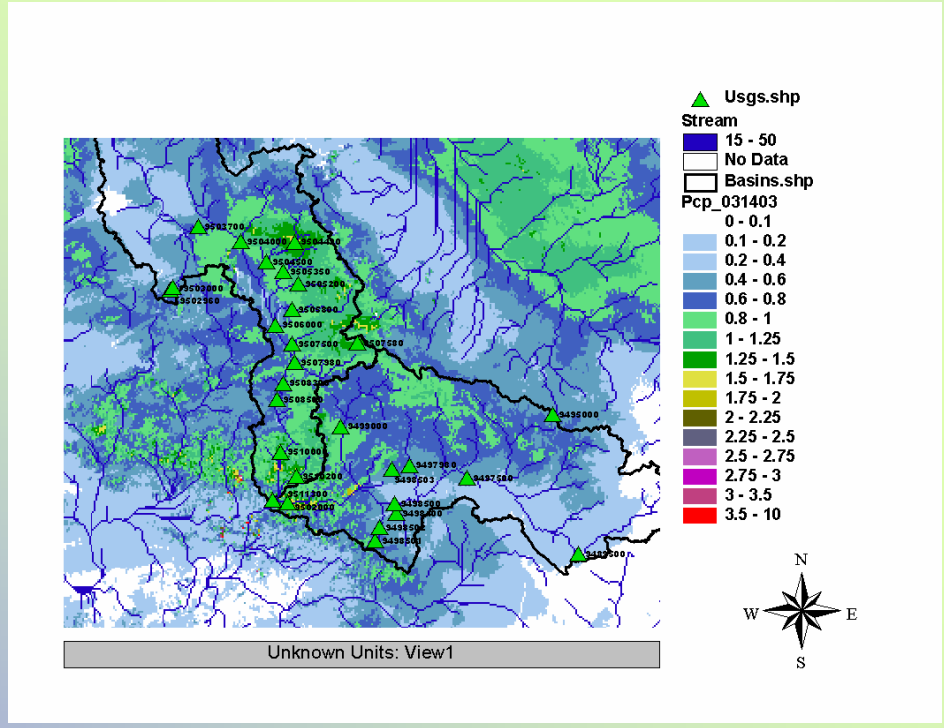
Tb = base temperature near freezing

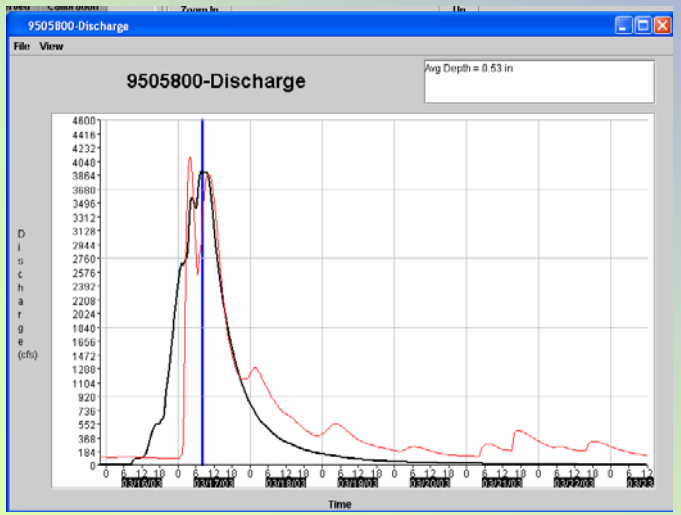
Salt River Project Arizona

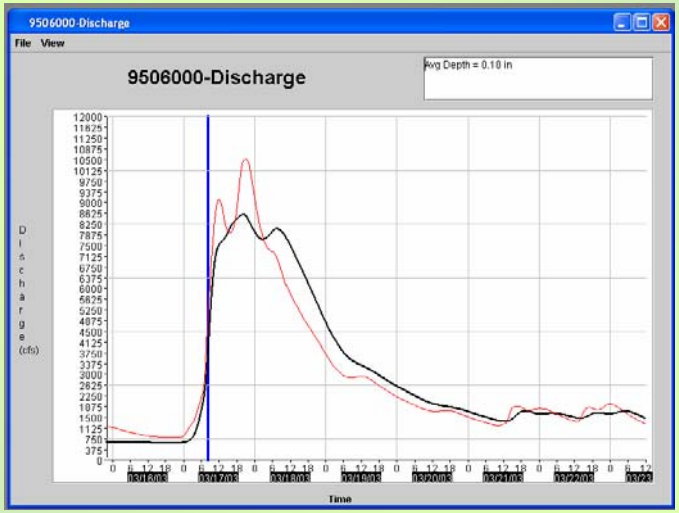
- Forecast inflow volume to reservoirs
- Snowmelt and rainfall during wintertime provide watersupply and hydroelectric power
- Without rainfall-runoff forecasts for reservoir inputs unintended release during flood conditions may result.



Storm Event March 2003







V*flo*™ Modules
(Version 2.1)

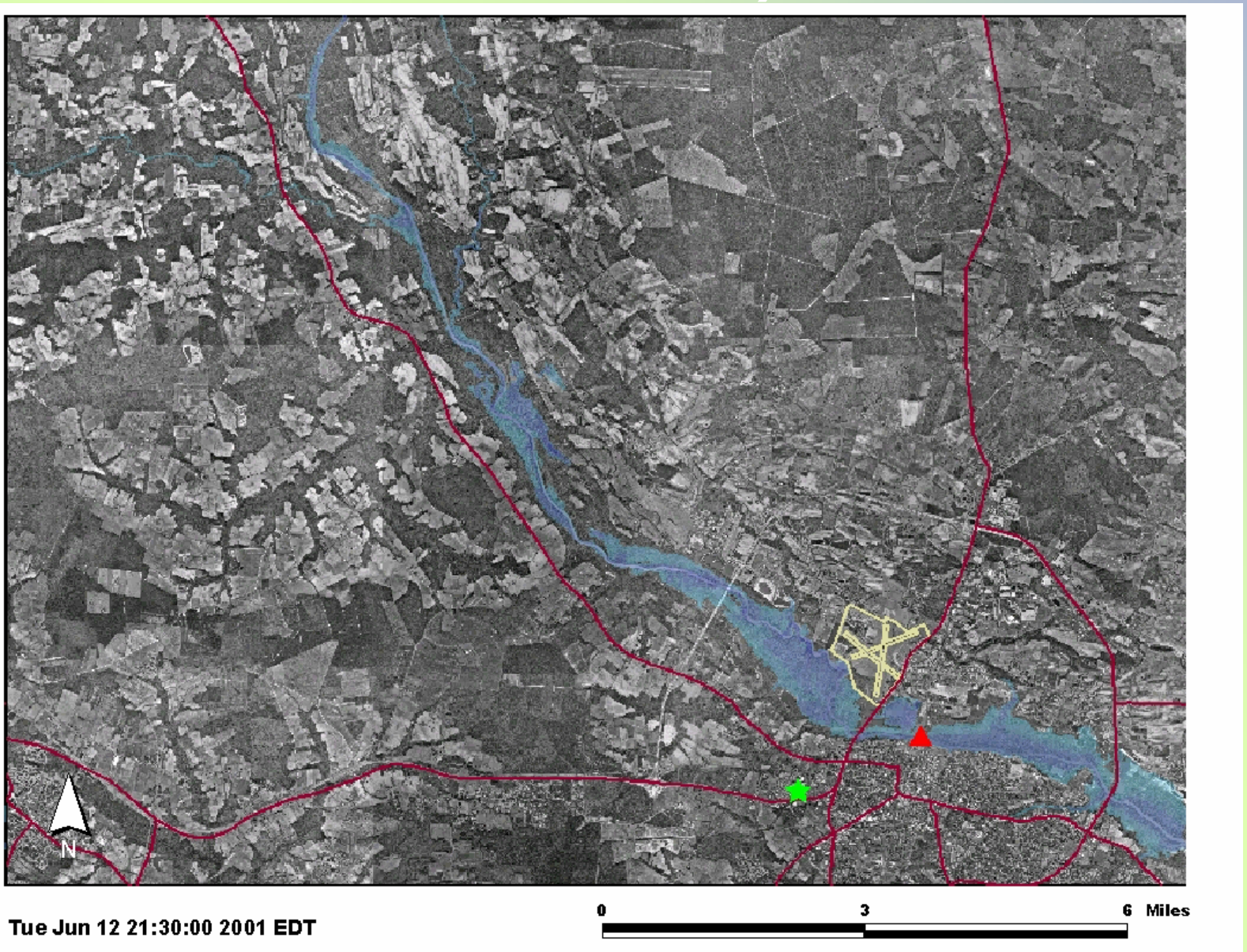
Inundation mapping

Distributed Inundation

Principles—

- Inundation mapping relies on a data structure for representing the water surface elevation in relation to the floodplain or other feature elevation.
- Flow depth added to invert elevation produces water surface elevation at each grid cell along a channel.

Inundation mapping
Tar River, NC



V*flo*™ Contaminate Transport

Version 3.x

Module

Contamination of Stormwater Runoff

- Unplanned releases of hazardous chemicals into streams and rivers pose a threat to human health, wildlife, and the ecosystem.
- Sources include industry, mining activities, agricultural and urban runoff.
- Toxic chemicals, both organic and inorganic, partition between the water and sediment in rivers.
- Bacteria, heavy metals, inorganic complexes, nutrients, and other types of contaminants may be transported by stormwater runoff.

Summary

- **V*flo*™ is commercially available physics-based fully distributed model**
- **Implemented in JAVA**
- **Distributed architecture**
- **Web graphics**
- **Integrated components viewable with GUI (Desktop)**
- **Real-time Server version for unattended and viewable with a web-browser**
- **Forecast system includes—**
  1. Precipitation processor for multisensor QPE and QPF input
  2. V*flo*™ server model
  3. Database server
  4. Web server
- **Free 30-day download at www.vieuxinc.com**

V*flo*™ Model Overview

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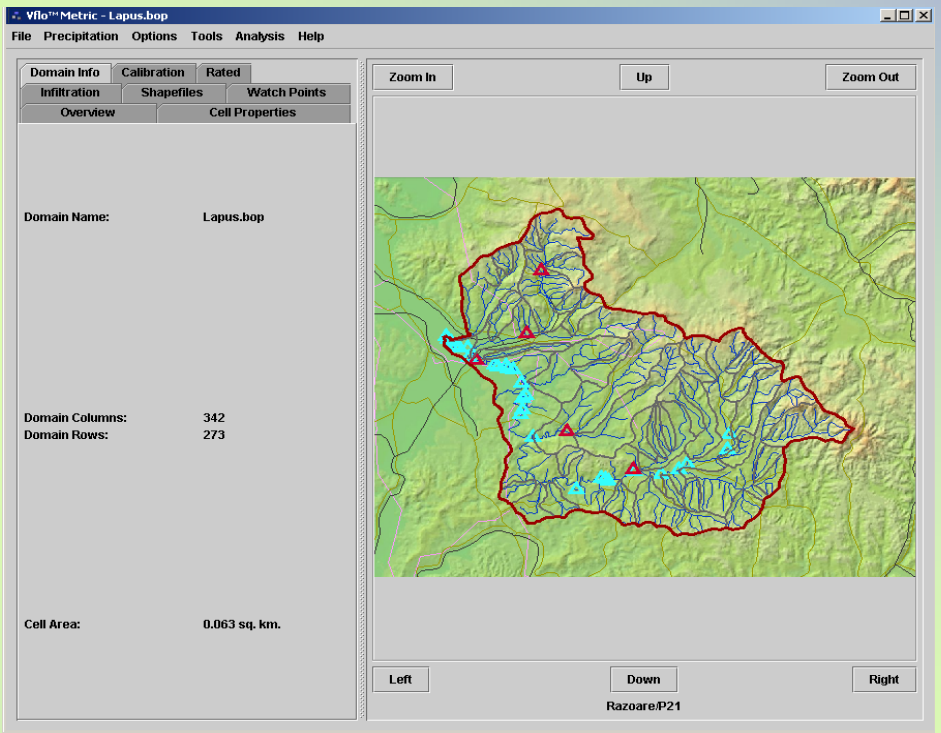
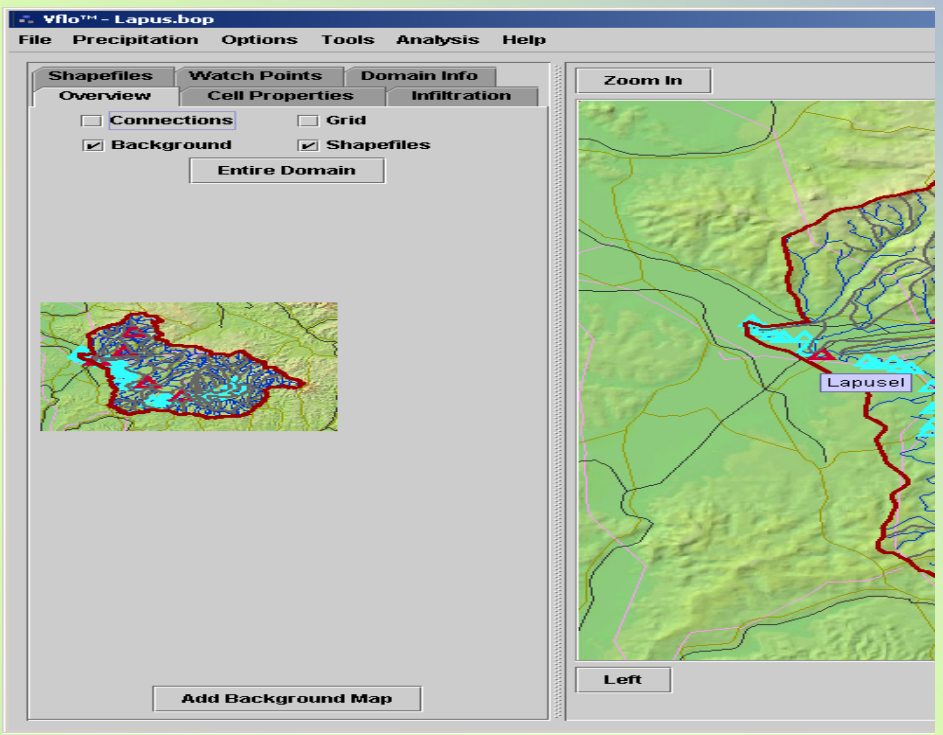
Domain Info

- Domain size in rows and columns, and the grid cell size
- Metadata entry to keep track of model development and calibration



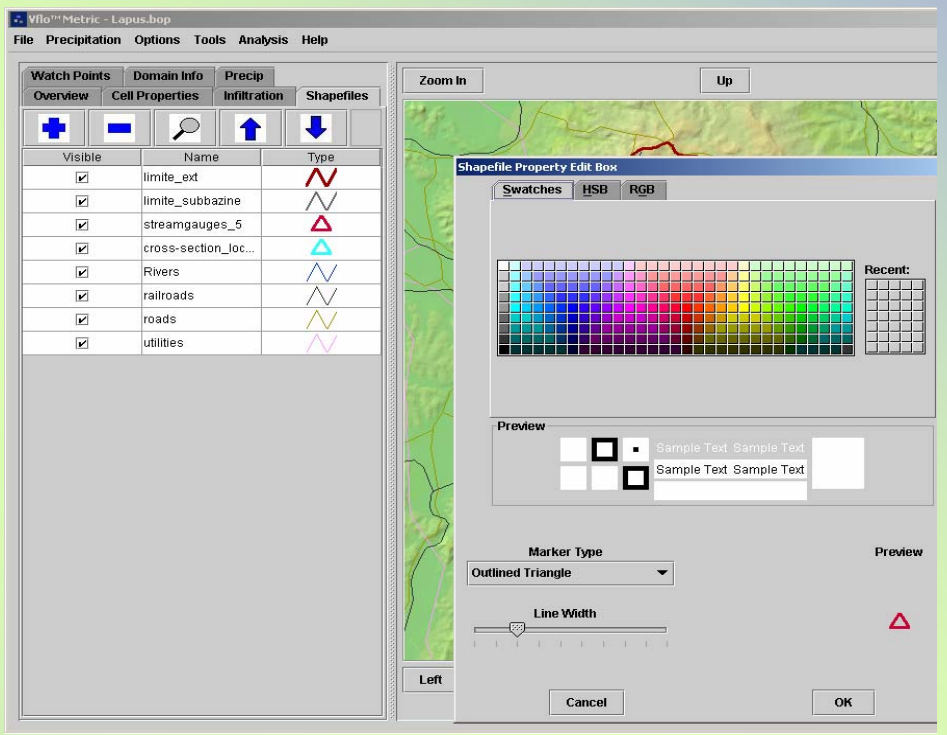
Overview

Grid cells, shapefiles, background image, and drainage connection display, and pan/zoom options available along with a locator box.



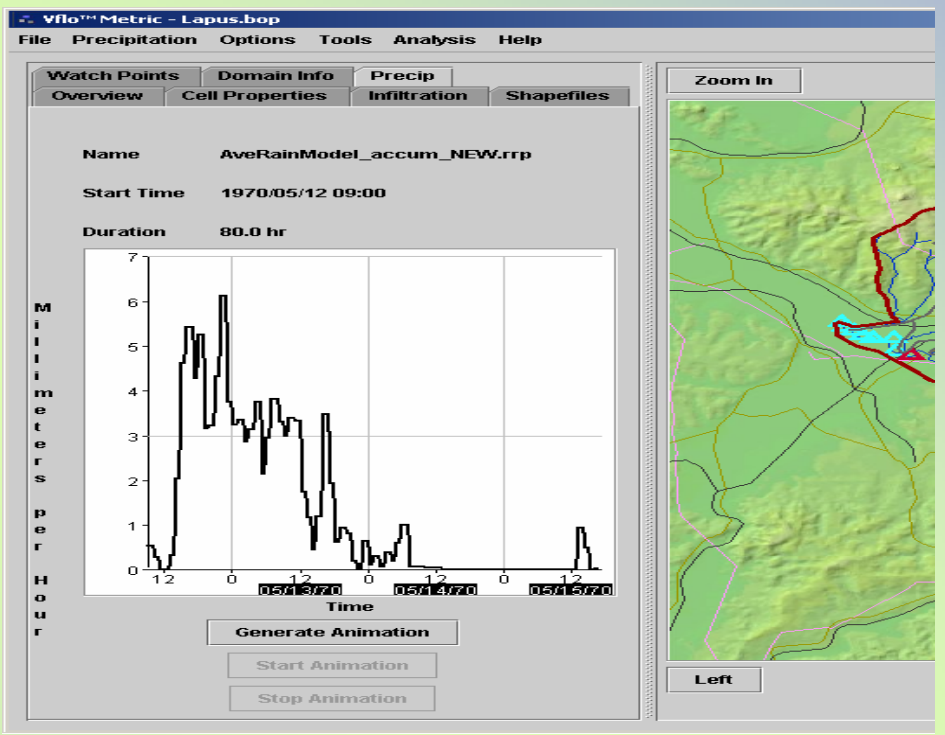
Shapefile

Controls the display of shapefiles showing features such as watershed boundary, stream gauge locations, and other important locations for user reference and orientation.



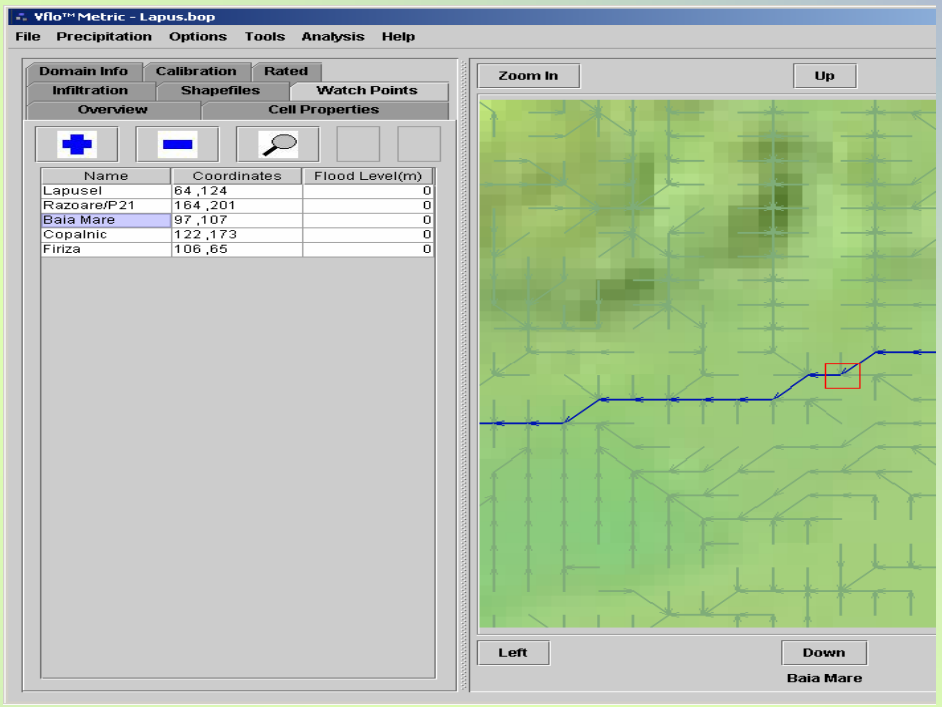
Precipitation

Displays hyetograph at a cell and rainfall map animation for a particular storm event.



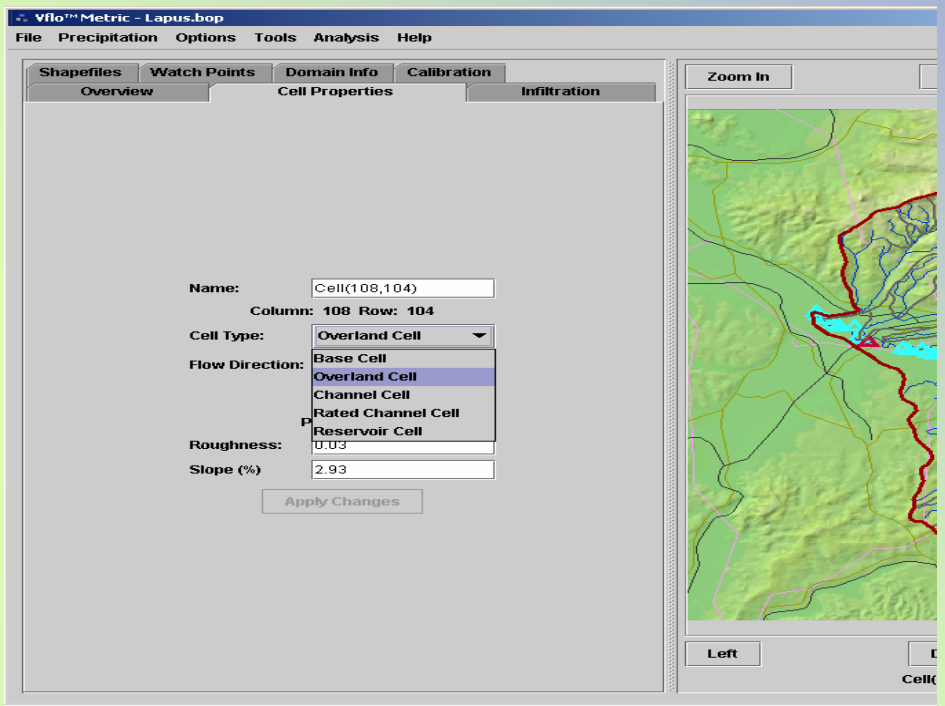
Watch Points

Automatic tracking of flood stage and other hydrograph information.



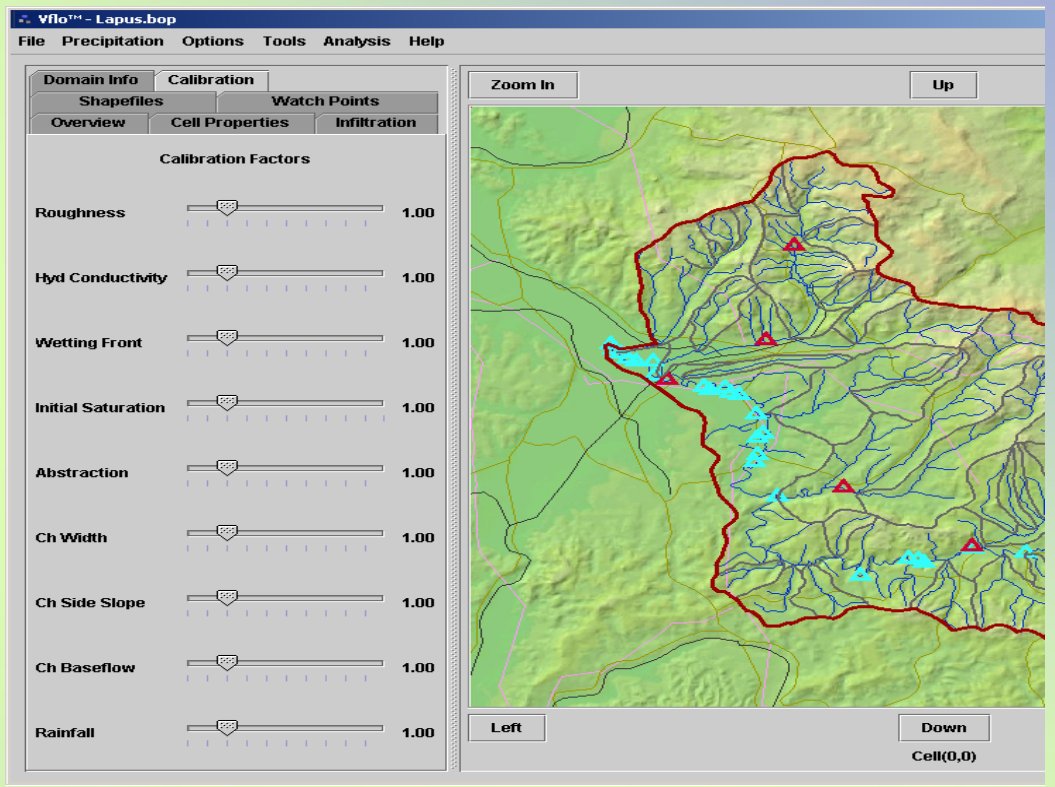
Cell Properties

Cell name, coordinates, flow direction, and slope/roughness properties. Cell types include base, overland, channel (trapezoidal), rated channel, cross-section, and reservoir cells.



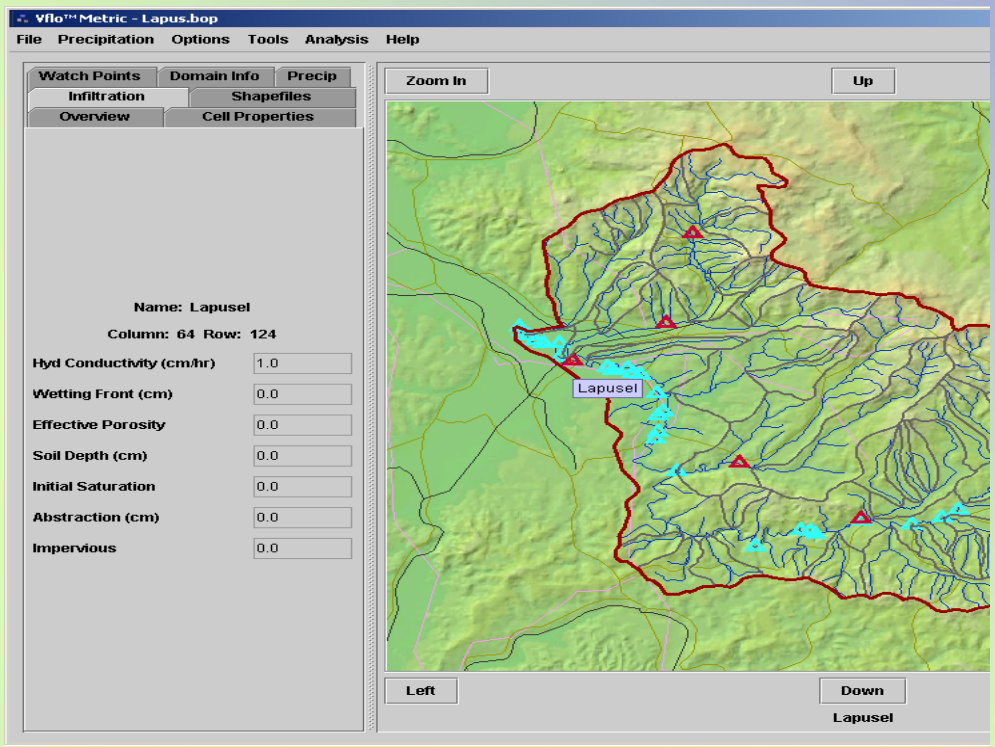
Calibration

- **Slider bars used to control multiplicative factors for adjusting parameters.**
- **Scales parameter values for entire domain, selected cells, or for selected drainage areas.**



Infiltration

Cell parameters related to Green and Ampt: Saturated Hydraulic Conductivity, Wetting Front Suction, Effective Porosity, Soil Depth, Initial Saturation, Abstraction, and Impervious.



Current Module Development (2003/2004)

Soil moisture module—

- Real-time evapotranspiration and soil moisture accounting (operational testing completion 12/2003).

Inundation module—

- Real-time inundation web display of flooded areas and flood risk (Desktop completed/Operational Testing 6/2003).

Planned Modules (2003/2004) cont'd

Water Management Dispatch—

- Water management and dispatch from reservoirs, diversions, and off-channel storage modeled with hydraulics included for pipes, inlets, and weirs.

Water Quality V*flo*™ Chem—

- Water quality modeling, load forecasting benefit from distributed modeling. Distributed point and non-point sources concentration and downstream arrival times. Water releases for environmental allocations and downstream dilution.

Software Demonstrations

- **Tutorial 1**
- **Tutorial 2**
- **Tutorial 3 Brays Bayou Roark Road**
- **Tutorial 4 Blue River DMIP Experiment**
- **Lapus Romania**